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THE COMPARATIVE EFFECTIVENESS OF POISONED BAIT AND SPRAYS FOR GRASSHOPPER CONTROL IN LYMAN COUNTY, S. DAK., 1947

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South-central South Dakota has been plagued annually by widespread or local outbreaks of the differential grasshopper (Melanoplus differentialis (Thos.)) since 1929. Other species have added to the damage wrought by M. differentialis, but it has been by far the worst offender. The climate and the type of agriculture, consisting of small grains, corn, and sorghum fields interspersed with native short-grass hay and pasture lands, are most favorable in this area for the maintenance of this species in numbers of annual economic importance.

The life history and habits of Melanoplus differentialis and the type of infestation it produces in southern South Dakota have made it difficult to control this species with poisoned bait. The main hatching period usually lasts throughout the entire month of June, a rainy period. Its eggs are deposited in sod land adjacent to dense, succulent crops and weedy places into which the hatching nymphs quickly move for the purpose of feeding. In such places it is often impossible to effect a good kill with poisoned bait spread among the young nymphs. Furthermore, the dense foliage in these places, under localized outbreak and late hatching conditions, usually affords enough food for the young hoppers without their seriously damaging the small-grain crop. Generally speaking, it is only when this crop is cut that the migrations of M. differentialis, then in the fifth, sixth, and adult stages of development, from the small-grain fields become an immediate threat to cultivated crops, mainly corn and the sorghums. Crop protection by a satisfactory reduction in numbers of this pest under such conditions of continued movement requires three or more applications of poisoned bait at a time when the farmers are harvesting their greatest cash and feed crop, the small grains.

1/ This work was conducted in cooperation with the Division of Grasshopper Control. Valuable assistance was rendered by the agricultural agent and other officials of Lyman County, and county facilities and equipment were made available for mixing, storing, and applying spray and bait materials.

The development of chlordane and toxaphene sprays, with their high efficiency and residual effectiveness as grasshopper insecticides, seemed to offer a way of overcoming some of the difficulties encountered in the use of poisoned bait. When vegetation is treated with these materials, grasshoppers have no choice of unpoisoned food such as they have when poisoned bait is used, and are poisoned whenever they feed. This is true not only of the grasshoppers present when the insecticides are applied but also, in varying degree, of those which hatch later in the treated area and of those which migrate into it. The time during which chlordane and toxaphene continue to kill depends upon weather conditions and dosages used, but the period generally extends from 1 to 3 weeks. This extended period seems particularly favorable to their effective use for controlling Melanoplus differentialis infestations in south-central South Dakota.

When poisoned bait is used, grasshoppers have a choice of food and may prefer succulent vegetation. In that event bait will be ineffective even though it is properly mixed and distributed. Another weakness of the baiting method under these conditions is that success depends upon the grasshoppers feeding heavily on the bait while it is still moist, since it loses much of its attractiveness to them after it has dried out.

Any grasshopper insecticide, to be useful to the farmer, must be not only effective under the prevailing conditions but also applicable and reliable enough to meet with his approval. To establish the worth of the three insecticides--chlordane sprays, toxaphene sprays, and poisoned bait--they were tested in actual control programs against local farm infestations in Lyman County, S. Dak., during the 1947 season.

Objectives

In these tests the ultimate measure of control resulting from the different treatments was the number of egg pods per square foot present in the egg beds at the end of the season. Good control was considered to be not only crop protection but reduction of infestations to the point where they ceased to be a threat for the following year or, with proper attention, for years to come.

Control efforts were divided roughly into two phases. All three insecticides were first used against infestations during the hatching period and early nymphal stages, when the young hoppers were still concentrated on the egg beds and along field margins. Later these insecticides were used against migrations of the late instars and adult hoppers moving into corn and sorghum fields from the harvested small-grain fields. In each test all the infested portions of a unit area were treated with the same insecticide. A unit test area consisted of a whole farm or section. Such large areas were necessary to do away with interference from outside infestations.

Materials and Methods

The poisoned-bait formula was that recommended by the Bureau of Entomology and Plant Quarantine. It consisted of 3 parts of sawdust and 1 part of bran (by volume) with 6 pounds of sodium fluosilicate per 100 pounds (dry weight) of the mixed bait. Enough water was added to this mixture so that a few drops could be squeezed out of a handful of the bait. A standard power mixing machine and power spreader were used to mix and spread the bait at the rate of 30 pounds of wet bait per acre. All baiting operations followed the general pattern of such operations in an organized county grasshopper-control program.

The chlordane spray consisted of 1 pound of chlordane dissolved in 1 quart of No. 1 distillate with 25 ml. of Igepal CA Extra High Concentrate (condensation product of ethylene oxide and an alkylated cresol), and water to make 4 gallons.

The toxaphene spray consisted of 2 pounds of toxaphene dissolved in 1 gallon of No. 1 distillate with 100 ml. of Igepal CA Extra High Concentrate, and water to make 4 gallons.

Usually 4 gallons of spray was applied per acre, although the actual dosage varied at times. All the sprays were applied with a sprayer of the high air-velocity blower type mounted on the back end of a $1\frac{1}{2}$-ton truck. This sprayer had a side delivery, which facilitated the spraying of borrow pits along roadways, fencerows, and field margins by keeping the truck on roadways or comparatively firm ground during wet weather. The stock spray solutions were made up in large quantities so that they could be carried out to the farms as such and then diluted from local tanks and wells as needed. All spray ingredients going into the spray tank were strained through a fine-mesh milk sieve to keep the nozzles from stopping up. The sprayer was calibrated to deliver 8 gallons of liquid with the truck traveling one-half mile at 10 miles per hour and covering a strip 2 rods wide. Since the prescribed speed could not always be maintained, the quantities used out of the spray tank were determined by means of a calibrated measuring stick, and speedometer mileages were recorded. The rates per acre were calculated from these figures. Although rather cumbersome at times, the blower type of sprayer applied the spray quickly and effectively under most of the field and margin conditions occurring in the test areas. Incidentally, the mixing and application of the sprays was much easier, simpler, and less disagreeable than the mixing and spreading of poisoned bait.

Whether dilute or stronger solutions of the spray or different quantities of bait per acre were used to meet certain conditions and urgent situations, all records were kept and summarized in pounds of wet bait or of chlordane or toxaphene per acre-application. The treated acreages given in this report as baited or sprayed are the actual acreages covered, irrespective of the number of times they may have been treated.

Costs were not considered in these tests. Only as much of an insecticide was used as was necessary to secure absolute control of the infestation. From the number of pounds used per acre given herein, costs may be calculated on the basis of current prices, whatever they may be.

Results

Table 1 affords ready comparisons of the results obtained with the three insecticides. The numbers of hoppers per square yard at the beginning and end of operations are estimates made at definite stages in an ever-changing population, the first during the hatching period and the second during the period of continuous migration after the small grain was cut. Because of the residual effect of the sprays in killing off the grasshoppers as fast as they hatched or moved into the sprayed area, the beginning population is not the total population concerned in the spray tests. For example, in test 9 the population is given as 1,000 per square yard for the margins and 1- for the field. Since this was the population when the spray was first applied on the margin and when only 50 percent had hatched, the total population in the margin could have theoretically reached 2,000 per square yard if no spray had been applied. In other tests, such as test 2, after early spraying had wiped out the infestations of immediate threat to a field, reinfestations came from adjacent harvested small-grain fields which had been lightly infested from untreated egg beds. Therefore, since both hatching and migration swelled the numbers of hoppers involved in any test, the percent reduction figures are conservative.

Most of the figures under "Percent of hopper damage" refer only to the damage to the ears of corn or the corn-grain yield. In tests 1, 5, 9, 10, and 11 the small grains were threatened with total destruction by the grasshoppers when the first applications of the chlordane and toxaphene sprays were made. For all other tests the small grains matured and were harvested without damage, regardless of any attempt to control the grasshoppers. The percentages of grasshopper damage might not have been so large if yields had not been limited by lack of moisture. In this section of the State, where a normal yield of corn is 40 bushels per acre, the severe drought in July and August reduced yields as much as 10 to 20 bushels per acre in the best fields. Whether yields are good or poor, the ears of corn damaged per acre by a given number of grasshoppers per unit area presumably would be about the same. The percentage of ears damaged is therefore a relative matter, and the same degree of control of the same intensity of infestation might result in a 10-percent loss in a year of poor yield and a 5-percent loss in a good year.

The last column in table 1 is a record of the average number of egg pods per square foot found in all the possible egg beds in the October egg survey of each test area. The sampling was restricted to grassy

Table 1.--Comparison of chlordane and toxaphene emulsion sprays and poisoned bait for control of grasshoppers in the field. Lyman County, S. Dak., 1947

Test No.	Crop and acreage	Period of operation	Number of applications	Total pounds used	Total acreage treated	Average pounds per acre	Number of hoppers per square yard				Percent reduction in population	Percent of hopper damage	Egg pods per square foot of margins
							Beginning of test		End of test				
							Field	Margin	Field	Margin			
						Chlordane Sprays							
1	Corn, 40 Cane, 10 Wheat, 50	June 16 to Aug. 12	5	54	31.6	1.71	1-	150	1-	2	95+	20 15 0	1.1
2	Corn, 140	June 16 to Aug. 5	4	24	20.6	1.16	1-	150	3	3	94	20	.7
3	Corn, 90	July 2 to 8	1	4	4	1	1-	20	1-	1-	95+	5	-
4	Corn, 90	July 2 to Aug. 6	2	24	22	1.09	1-	20	1-	4	80+	15	1.3
5	Barley, 50 Corn, 50	July 2 to Aug. 11	3	54	60	.90	150 1-	500 500	1- 1-	2 2	100 100	0 5	.4
6	Oats, 35 Corn, 40	July 28 to Aug. 11	5	35	28.8	1.22	1-	60	1-	2	100	0	.3
7	Corn, 40	Aug. 5 to 11	1	60	40	1.50	25	50	3	8	88	25	1.
8	Flax, 50	Aug. 7 to 10	1	60	50	1.20	20	20	20	20	0	70	-
						Toxaphene Sprays							
9	Small grain, 100	June 18 to Aug. 8	3	20.3	11	1.84	1-	1000	1-	1-	100	0	.9
10	Corn, 1.5 Wheat, 30	June 18 to Aug. 8	3	25.5	15.5	1.64	1-	600	1-	7	99	15 0	.9
11	Wheat, 47	June 18 to Aug. 11	1	30	15	2	200	600	1-	3	100	0	.6
12	Corn, 75	July 28 to Aug. 11	3	50	32	1.56	1-	100	2	3	95+	3	2.8
13	Alfalfa, 13	Aug. 15 to 23	1	24	13	1.84	60	60	2	2	96+	-	-
14	Alfalfa, 18	Aug. 15 to 23	1	26	18	1.44	40	40	6	6	85	-	-
15	Wheat, 160 1/	June 17 to July 3	2	12	6	2	1-	250	1-	1-	100	-	-
16	Wheat, 160 1/	June 23 to July 3	1	12.8	6	2.13	1-	50	1-	1-	100	-	-
						Poisoned Bait							
17	Small grain, 80	June 19 to 29	3	2200	72	30.5	1-	100	45	1-	5	-	-
18	Wheat, 160	June 19 to 27	2	650	22	29.5	1-	200	20	1-	10	-	-
19	Corn, 100	July 29 to Aug. 10	3	5050	156	32.4	3	25	1	6	70	50	1.9
20	Wheat, 30 Corn, 50	July 28 to Aug. 10	4	5900	185	31.9	20	40	3	18	85	0 90	7.4
						Untreated Field							
21	Corn, 80		0	0	0	0			25	100	0	100	9.9

1/ Treated with a concentrated solution of toxaphene in No. 1 distillate.

roadways, prairie margins, or fence rows adjacent to or a short distance from the fields. The sampling procedure followed was the same as that used by the Division of Grasshopper Control in its general survey of egg abundance, except that a greater area was included and more square-foot samples were taken in surveying the areas marginal to each field than would have been taken in the general survey.

Examples of Actual Tests

Since a comprehensive account of the problems and conditions that influenced the work performed in conducting each test could not be given in table 1, diagrams of six test areas are shown (figs. 1, 2, and 3.) The dotted portions of the diagrams give some idea of the proportion of the areas that were actually sprayed or baited during the season to produce the results shown in table 1. They also show where the spray or poisoned bait was applied. Each row of marginal dots represents a sprayed strip 2 rods wide. Some of these areas were sprayed twice, and two of them three times. In the bait test, parts of the dotted areas were treated three or four times. The numbers in circles correspond to the test numbers shown in table 1. All possible egg beds affected by each infestation were surveyed for eggs in October, and the numbers of egg pods per square foot found at each place at the end of the 1947 egg-laying season are recorded in the diagrams at each place surveyed.

Chlordane Emulsion Sprays

In test 1, 54 pounds of chlordane was applied to 31.6 acres to protect a 100-acre contoured field composed of 40 acres of corn, 10 acres of cane sorghum, and 50 acres of wheat, all in strips as shown on the diagram (fig. 1,A). Egg infestations before hatching had averaged 17 pods per square foot along the west edge, 2 to 6 along the east and north edges of the field, and 2 to 6 around the 200-acre wheat field to the east. Corn in the countoured field had been destroyed by grasshoppers in 1946.

During the first week of June 1947, the highway borrow pit was sprayed once. On June 16 and June 26, a total of 6 pounds of chlordane was applied on 6 acres of the egg bed on the western margin in which hatching was in progress. When 40 percent of the eggs had hatched, the population of nymphs was 150 per square yard. On July 2, 4 pounds was applied on 3.6 acres of the roadway and margin to the east, where hatching was complete and the infestation was 60 per square yard. The single applications killed all the hatched hoppers and remained 100 percent effective for 10 days. On August 6 the margins of the corn and sorghum strips, as indicated by the dots in the diagram, were sprayed with 12 pounds on 10 acres. Populations at this time ran 4 to 8 hoppers per square yard in the corn.

About August 10 the 200-acre wheat field to the east was cut, and a general migration from this field into the southeast corner of the contoured field took place. By August 12 a population of 30 hoppers per square yard, fifth- and sixth-instar and adult Melanoplus differentialis, was riddling the eastern third of the standing crop. On this date 32 pounds of chlordane was sprayed on 12 acres of the roadway, fence row, and eastern third of the corn and sorghum strips, as shown in the diagram. Twenty-four hours later more than 95 percent of the grasshoppers were dead or dying, and the residual effect on incoming hoppers lasted 26 days. The dead numbered at least 200 per square yard in the sprayed area on September 8, with a population of less than 1 live grasshopper per square yard left. Most of these were dying. Grasshopper damage to the corn was held to 20 percent and the number of egg pods from 1 to 1.4 per square foot, as shown in the diagram.

This test illustrates that light, or noneconomic, egg infestations of 4 or less egg pods per square foot in the marginal areas, producing 10 or less hoppers per square yard in the small grain, become a definite threat to adjacent corn when the small grain is cut. It also demonstrates that these corn or sorghum strips can be used as trap crops for reducing infestations to a minimum by treatment with an effective spray. The cane sorghum strip in this test took the brunt of the migration. It made a better trap crop or barrier than did the corn, because of the lower growing and denser foliage in which to trap the hoppers and check the migration. It was also easier to spray the shorter cane plants and to obtain a good distribution of the spray on the foliage than it was to spray the corn plants.

Test No. 5 was an attempt to save a 100-acre contoured field of barley and corn (fig. 1,B) from total destruction from a grasshopper population of 150 per square yard in the barley. In the field margins, mostly weedy, they numbered 300 per square yard in an area 4 rods wide. In the weedy draw shown in the southeastern quarter of the field there were 500 per square yard. Altogether there were about 15 acres of weedy margins. This infestation came from all four margins, where the egg pods had averaged 10 to 30 per square foot. Hatching was practically complete, and the nymphs were in the first to third instars. All the hoppers were in the margins and in the barley, which was headed out. The corn was a foot high and, although it was free of hoppers, the situation looked hopeless.

On July 1 and 2, 42 pounds of chlordane was applied to 50 acres of barley and weedy margins, including the weedy draw. Except for a small wet spot in the barley, this one application completely destroyed the initial infestation, and the results were quite spectacular to all those who saw them. A second application of 6 pounds on July 29 was sprayed on 4 acres in strips 2 rods wide along the edges of the corn. A reinfestation of these margins had come from outlying weedy places and the small untreated area in the barley which had been too wet to spray during

the first application. Again on August 4 a third application of 6 pounds on 6 acres of corn margins was necessary as a mopping-up measure. Populations in the first 5 rows of the corn amounted to 10 to 15 hoppers per square yard in places, but less than 1 in the middle portions of the corn strips. This last reinfestation came from neighboring small-grain fields which had been cut the last week of July. In both of these latter sprayings of the corn margins, the spray was blown directly into the corn and covered the first 10 rows. All the grasshoppers died within this sprayed area and no live hoppers got beyond it. The population in the corn strips themselves never reached 1 hopper per square yard.

There was no damage to the barley and not more than 5 percent to the corn. Fifteen hundred bushels of barley were harvested from the 50 acres and the owner expected the corn to yield between 10 and 20 bushels per acre. Without spray, these fields would have yielded nothing. Furthermore, as shown in the diagram, the 1947 fall survey of egg pods in the beds surrounding the field averaged only 0.2 to 0.8 per square foot. The egg infestation in the previous spring and fall averaged about 20 pods per square foot in these places. Thus there was a 98-percent reduction in egg infestation due largely to spraying 54 pounds of chlordane on 60 acres.

In test 6, on the quarter section to the west of the area included in test 5, there was a 40-acre cornfield almost surrounded by adjacent small-grain fields. Along the south edge of this cornfield there was a strip of prickly wild lettuce, 10 feet wide and head high, which was utilized as a barrier in the spray operations against migrations from the oat field to the south. This oat field was weedy and at harvesttime contained a population of 8 grasshoppers per square yard. There was a weedy shallow draw 2 to 4 rods wide running diagonally through the oat field, which had a population of 60 per square yard. Along the north edge of the corn, there was a sparser weedy barrier 6 feet wide, and on the west edge there was a somewhat weedy field road (fig. 1, B).

The eastern margin of this cornfield had already been protected by the early spraying operations in test 5. When the small grain was cut in the half of the section where this cornfield was located, a concentration of 60 grasshoppers per square yard developed in a strip 10 rods wide along the south edge of the corn. The grasshoppers were kept out of the corn by the 10-foot barrier of prickly lettuce. Another concentration of 40 hoppers per square yard, which had penetrated into the corn for 1 rod, developed in a strip 3 rods wide along the north and west edges.

On July 28, 12 pounds of chlordane was sprayed on 10 acres, consisting of the weedy draw, a strip 2 rods wide adjacent to the western edge of the corn and including 5 rows of the corn, and the 10-foot weed barrier just south of the corn, together with a 5-rod strip of the adjoining oats. The initial kill was 70 percent. A second application was made on July 30 of 12 pounds on 10 acres, including the south 5 rows of the corn, the 10-foot weed barrier, and an adjacent 10-rod strip of the oats.

In this area the hoppers numbered 60 per square yard. Another strip 4 rods wide along the north edge of the corn was included in this application. Here the population was 40 hoppers per square yard and the infestation had come from the wheat crop to the north, which was just being cut. For the south margin this was the second and last application. The infestation here, which had come from the oats, was practically wiped out with the two sprayings of the barrier.

On August 4, 6 pounds of chlordane was applied on 6.4 acres, consisting of the draw and a strip 4 rods wide along the northern edge of the corn. On August 8 another 5 pounds was applied on a 2.4-acre strip along the northern margin. The 6-foot sparse weedy barrier and the first 5 rows of corn were treated with the three applications made along this northern margin, together with an adjacent 2- to 4-rod strip of the wheat stubble. These sprayings were on places where the movement from the harvested small grain to the corn was continuous. The object of these repeated applications was not to let these migrations get beyond the first 5 rows of corn.

On August 11 the populations were 1 to 2 hoppers per square yard along the weedy barrier on the southern margin, less than 1 in the corn, small-grain stubble including the oats, and the weedy draw, and 3 to 8 per square yard in a strip 1 rod wide along the north edge of the corn.

The damage to the corn was held to less than 1 percent and the hopper population reduced almost 100 percent. The damage would not have been noticeable except that the first 2 rows along the north edge of the corn were completely destroyed. Since there were few weeds along that edge which could be used as a barrier to protect the corn, the first 5 rows had been used as a barrier. Along the south edge the 10-foot barrier of sprayed weeds saved even the first row of corn from damage, although the populations here had been three times as great as those along the northern edge.

The yield of corn was estimated to be 10 to 20 bushels per acre, a low yield due to dry weather, but without spraying all the crop would have been completely destroyed. In the egg survey made after control operations, the number of pods averaged 0 to 0.8 per square foot in all the possible egg beds, as shown in the diagram. In the combined operations on tests Nos. 5 and 6, in which 89 pounds of chlordane was sprayed on 88.8 acres, 90 acres of corn (1800 bushels) and 50 acres of barley (1500 bushels) were saved from total destruction, and the potential egg infestation was reduced more than 95 percent.

This farm is one of several that have suffered partial or total crop losses from grasshoppers every year since about 1930. In this area and on this farm poisoned bait had been used as recommended but, according to the farmer, with poor results. In 1947 this farmer and his neighbors saw for the first time a grasshopper infestation almost completely destroyed and more than 95 percent of the crop saved by control operations.

Toxaphene Emulsion Sprays

Tests 9 and 10 can be considered as one operation in the spraying of egg beds during the hatching period. Test 9 was conducted on a prairie margin where the egg pods averaged 13 per square foot and test 10 was conducted on a grassy roadway averaging 7 pods per square foot. On June 18 the hatch was 50 percent complete. The population in the area included in test 9 ran 1,000 hoppers per square yard in a winter wheat strip 3 rods wide, and 500 on an egg bed 2 rods wide adjacent to the south. In the area included in test 10 the population was 600 per square yard along the roadway. On that date 10 pounds of toxaphene was applied to 5 acres in test 9 on the winter wheat strip and egg bed. On the same day 10 pounds was applied on 6 acres in test 10 along the roadway and along the east and north margins of the wheat. The dotted areas on the diagram (fig. 2,A) show where these applications were made.

At this time the owner of the farm planted a strip of corn 16 rods wide by 80 rods long along the south edge of the wheat in the southwest quarter of the section. This corn strip was planted as a trap crop for later spraying to control grasshoppers migrating from harvested small-grain fields.

Continuous hatching of the eggs took place in both tests from June 18 to July 1, when all hatching was completed. Heavy hatching was noted on June 20, 23, and 26. The first application of the spray wiped out the initial infestations, mostly first instars, in both tests. After the first application in test 9 another heavy infestation built up on the egg bed in the southeast section as the hoppers hatched out. After each period of heavy hatching the reinfestation was destroyed by the residual effect of the poison from the one application. The newly hatched nymphs were not able to move more than 2 rods from where they hatched before they succumbed to this residual action of the toxaphene. These nymphs were often found in a dying condition immediately after hatching while they were still whitish in color. The toxaphene spray applied on June 18 continued to kill newly hatched nymphs on the area sprayed until July 1, when the hatch was completed.

A total rainfall of 0.58 inch in several showers on June 21 to 22 and on June 29 had no adverse effect on the residual activity of the poison in test 9 or in test 11, which was conducted in the next section to the west.

Supplementary areas were sprayed in both tests 9 and 10. In test 9 6.7 pounds of toxaphene was applied on July 1 to 3 acres of weedy patches at the ends of the original area, and on August 8, 3.6 pounds was applied on 3 acres of fence row and other weedy places. In test 10, 3.5 pounds was applied on June 26 to 4.5 acres of the roadway because of poor coverage in the first application, and 12 pounds was applied on August 8 to 5.5 acres consisting of the $1\frac{1}{2}$-acre corn strip and the

roadway on the east. Part of the corn strip and wheat stubble on the east side had developed an infestation of 40 hoppers per square yard over 1 acre. There was also some concentration along the roadway, and all of the infestation came from the egg bed on the northern edge of the small-grain fields in the east half of the section.

Populations at the end of the operations in both test 9 and test 10 were reduced to less than 1 hopper per square yard in the field and 3 in the weedy margins. The number of egg pods found in the October egg survey averaged from 0 to 2.7 per square foot in the seven places examined and 0.8 pod per square foot for all egg beds on the section, which was at least a 92-percent reduction from the number of egg pods found in the spring egg survey. The corn strip in test 10 showed a total of 15-percent damage to the ears, mostly in the east end for 0.1 mile. As indicated by its location in the diagram, this strip of corn would have been subject to severe damage by grasshoppers coming out of adjacent small-grain fields if nothing had been done to suppress the severe infestations therein. Yet a corn crop estimated at from 15 to 20 bushels per acre was made. The oat field in the east half of the section just north of the area included in test 9 would also have been severely damaged or possibly destroyed by the severe infestations along the south and west edges if no spraying had been done. The owner estimated that a 60-bushel crop was harvested from this field. For a total of 45.8 pounds of toxaphene applied on 26.5 acres, at least 130 acres of small grain, which included part of the wheat in the west half, were saved and the infestation was almost wiped out.

In test 11 a 47-acre wheat field was threatened with total destruction by an invasion of grasshoppers hatching on the prairie-margin egg beds to the north and west of the field (fig. 2,B). On June 18 this invasion had reached 10 rods into the field from the north and west, with an average population of 600 per square yard over 15 acres. The egg bed to the north, on the basis of the empty egg pods found, averaged about 30 pods per square foot before the eggs hatched. The wheat was 12 to 15 inches high and was being destroyed. Furthermore, 20 rods to the north was a 25-acre corn strip and still farther north in the same half-section another cornfield 50 acres in size, both of which were threatened by this infestation.

On June 18, 30 pounds of toxaphene was sprayed on 15 acres of the wheat field and weedy margins, as shown by the dotted area in the diagram. Because of a half-acre patch missed in the northwestern corner of the field during the spraying operation, it took 8 days for the infestation in the field to disappear. On June 26 a few newly hatched nymphs were observed making their way into the weedy margin of the field from the egg bed on the north, but these nymphs were dying within the first 2 rods across the sprayed area and none penetrated farther into the field. On June 29 hatching was completed and a few first-instar

nymphs were found in a dying condition in the first 2 rods of the weedy margin to the north. There were no grasshoppers in the wheat field itself on that date.

A survey of adults made on August 11 showed an average of 3 hoppers per square yard in the 2-rod-wide weedy margin and other margins of this field after the wheat was cut, but none in the wheat stubble. The owner reported a crop of 15 bushels per acre on the 47 acres, a poor yield due to poor soil and a poor stand. Nevertheless, the two cornfields to the north owed their survival in part to this one application of the spray.

Test 12 was a late spraying to save two cornfields in the quarter-section north of the area included in test 11 from migrations from adjacent small-grain fields during harvest. Three applications were made in the dotted area shown in the diagram (fig. 2, B). On July 28, 20 pounds of toxaphene was applied on 10 acres of the north and west margins of the 25-acre corn strip and north and east edges of the adjacent wheat strip. Again on July 30, 12 pounds was applied on 12 acres of the same margins. A third application of 18 pounds on 10 acres was made on August 4. This third application included the roadway along the northern edge of the quarter section. Infestations in the sprayed areas ran 50 to 100 hoppers per square yard, mostly fifth- and sixth-instar and adult Melanoplus differentialis. In spite of excellent kills with each application, these numbers were maintained by continuous migrations until the third application destroyed most of the remaining grasshoppers coming from the oats to the west and the wheat strip between the cornfields.

There was no natural barrier along the north edge of the 25-acre corn strip, so the first 10 rows of corn was used as such. Three applications on this barrier piled up the dead hoppers in the sprayed area and held damage to the first 5 rows. Here damage was graduated from stalks eaten to the ground in the first row to damaged stalks of normal height in the fifth row. In the same area on August 11, 7 days after the last spraying, there were still freshly dead and dying hoppers, and the population in the corn was 2 per square yard and 7 in a strip 1 rod wide along this north edge. The infestation in the 50-acre cornfield to the north was less than 1 hopper in the field and averaged 3 along all margins.

Estimated reduction in corn yield amounted to 6 percent in the 25-acre field and less than 1 percent in the 50-acre field. The estimated yield in both fields was 20 bushels per acre.

For the areas included in tests 11 and 12, therefore, 80 pounds of toxaphene on 47 acres saved 47 acres of wheat and 75 acres of corn. The number of egg pods in the possible egg beds of any consequence was also held down to 0 to 3 per square foot. The 7 pods per square foot shown at the west edge of the alfalfa patch in the northeast quarter and the 10 pods per square foot adjacent to the northwestern corner of the

milo field in the southeast quarter represent only very small egg beds. The true average egg infestation for all the field margins on the half section by the end of the 1947 season was about 1 pod per square foot.

In some of the late spraying on this section, at an air temperature of 107° F., the residual effect lasted only 5 to 7 days, as compared with 10 to 14 days from the early spraying at the same dosages.

Poisoned Bait

Test 17 was an unsuccessful attempt to control hatching nymphs along the margin of a wheat field and prevent their spreading into the crop (fig. 3,A). The spring egg survey showed an average of 10 pods per square foot in the prairie margin across the road to the west and 4 in the adjacent prairie margin to the north of the wheat field.

On June 19, 500 pounds of wet bait was spread on 12 acres of field margin to the north and west. On June 25 the infestation had spread into the field from these directions to a depth of 10 rods, as shown by the dotted lines and area in the diagram. The population in this area averaged over 100 hoppers per square yard, and less than 5-percent kill was obtained with the first baiting. The infestation extended over 25 acres on that date, and it was baited with 700 pounds of wet bait. Not more than a 10-percent kill was obtained with this second baiting. By June 27 the infestation had moved another 10 rods into the field and 1,000 pounds more of the bait was spread on 35 acres, which included most of the field infestation. This application did little or no good, and baiting operations were discontinued here, as the hoppers were not being checked in their spread through the wheat field. A similar attempt in test 18 (see table 1) to obtain control by the early baiting of nymphs on the egg beds and along the margins of the fields was also ineffective.

Test 20 was an attempt to save corn in strip plantings of an 80-acre contoured field of wheat and corn (fig. 3,A) from an infestation which developed from 5 to 10 egg pods per square foot in the grassy margins around the field. An abortive attempt to stop the newly hatched hoppers from moving into the wheat strips was made on June 25, when 50 pounds of wet bait was spread on 2 acres of the roadway on the east. By July 28 the population in the corn strips was 20 hoppers per square yard and in the margins 40 to 50, mostly fifth- and sixth-instar and adult Melanoplus differentialis, and there was 20 percent damage to the ears.

Four applications of bait were made as follows: On July 28, 1,500 pounds of wet bait on 50 acres of the corn itself and weedy margins; on July 30, 1,600 pounds on the same area; on August 1, 1,800 pounds on the same area and on margins of the wheat-stubble strips, 55 acres in all; and on August 6, 1,000 pounds on 30 acres of the still heavily infested places.

With the first three applications, beginning July 28, the population in the corn rows was reduced from 20 to 10, from 10 to 6, and from 6 to 3

per square yard, respectively. Although more bait was spread on the weedy fence row and roadside on the north and other weedy places than elsewhere, the populations remained 20 to 40 hoppers per square yard in these weed patches. A final survey of adults on August 10, after the fourth application, showed 1 to 4 per square yard in the field and 18 in the weedy fence row and margin on the north.

A survey on September 9 showed a 90-percent loss of ears from hopper damage and a reinfestation of 4 to 8 hoppers per square yard in the corn. From July 28 through August 6, 5,900 pounds of wet bait was spread over 185 acres in four applications. The population was reduced 85 percent, but the damage to the ears had been done. Furthermore, the survey in October of the egg beds surrounding this field, as shown in figure 3, averaged 1.7 to 15 pods per square foot, or an average of 8.2 pods for all the egg beds. The average in the spring survey had been 6.2 pods; so it is apparent that the baiting program as actually conducted not only resulted in unsatisfactory control during the current season but also did not reduce the prospect of severe infestation the following year.

This test may appear to be an untimely one, because baiting was not started until after the wheat strips were being cut and the hoppers were moving into the corn. However, this situation is typical of the locality. The wheat was not being damaged, and the owner did not want anyone driving through this field in what might prove to be a vain attempt to control the infestation in the wheat. In test 17, an attempt had been made, without success, to check the early movement of the hoppers into the small grain, and there was considerable evidence that control could not have been obtained in the wheat in the area for test 20. Since all the conditions of the area for test 20 were common to the locality, they were accepted as typical and the test was made. For a direct comparison with the situation found in the area for test 20, however, chlordane spray (test 7) was used on a 40-acre cornfield containing a heavier infestation of 25 grasshoppers per square yard in the field and 50 along the margins, and where damage to the ears had already amounted to 20 percent. The results of the two tests are compared under the heading "Other Tests in Table 1."

Test 19 was an attempt to protect by use of poisoned bait 100 acres of corn from grasshoppers migrating out of small-grain fields that had been harvested (fig. 3, B). Three applications of the bait were made as follows: On July 29, 900 pounds of wet bait on 23 acres, once around the field and into the field from the south; on July 31 and August 1, 1,650 pounds on 50 acres of the corn and a 3-acre strip 8 rods wide into the oat stubble to the south; on August 8, 2,500 pounds on the entire 80 acres in the cornfield. On these dates the populations in the baited areas were 10, 7, and 5 per square yard, respectively. These numbers were less than a third of those encountered in any of the other bait or spray tests.

Not much was accomplished with the first two applications, but by August 10, after the third application, the population had been reduced

70 percent. On that date the average was less than 1 hopper per square yard in the field and 4 to 7 along the margins. On September 9 a reinfestation of 5 hoppers per square yard was observed in the corn. This reinfestation had come from adjacent small-grain fields that had been cut. On the 100-acre area protected by test 19, 5,050 pounds of bait was used on 156 acres.

During the 10-day period from July 29 to August 8, grasshoppers continued to damage the ears until only a 50-percent yield was possible. There was only one-fourth to one-half a crop because of the dry weather. If weather conditions had permitted a good yield, the percentages loss would have been proportionately lower or around 20 percent. In view of the short crop, however, the only saving here would have been to forego control so that the materials and effort used in the baiting operations would not have been wasted. This argument overlooks the beneficial results of a 70-percent reduction of the original population but does follow the reasoning of the farm operator. The fall egg survey showed that the number of egg pods around this field averaged 0.8 to 2.4 per square foot. This is a noneconomic infestation. However, when these figures are compared with those from the spray tests, it must be remembered that the grasshopper populations in all the spray tests were many times greater.

Other Tests in Table 1

Control practices similar to those described in the previous paragraphs were used in all the other tests listed in table 1, and some mention should be made of them.

For chlordane, tests 2, 3, and 4 were mainly the early spraying of egg beds in uncultivated margins adjacent to fields containing crops followed by mopping-up applications. Test 7 deserves special discussion because it was on a 40-acre cornfield when the corn was 6 to 8 feet high and infested with late-instar nymphs and adult Melanoplus differentialis numbering 25 per square yard in the field and 50 along the margins. This migration had come from harvested small-grain fields adjacent to the north, east, and west edges of the field. The corn was being stripped of leaves, tassels, and silks. On August 5, 20 percent of the ears were damaged, and there was a heavier infestation in taller and denser corn than in poisoned-bait test 20 (fig. 3,A) with which it may properly be compared.

On August 5, 60 pounds of chlordane was sprayed over the entire 40-acre cornfield of 200 rows of corn, one-half mile long. Thirteen trips lengthwise of the field were made in which 2 rows each trip or 26 rows altogether were knocked down by the truck on which the sprayer was mounted. The end result, given in table 1, test 7 for chlordane, shows a reduction of 88 percent in population and holding of further loss due to hopper damage to 5 percent, not including the total loss of the

26 rows or 13 percent of the corn knocked down in applying the spray. There was an estimated total loss of only 25 percent due to the grasshoppers, as compared with bait test 20 in which there was a 90-percent loss, and the yield was about 10 bushels per acre. The residual effect of the spray lasted 10 days and was reflected in a much reduced egg infestation averaging 1 pod per square foot for all the possible egg beds affected by this infestation.

Test 8 with chlordane was the one failure in all the spray tests. This spray was applied to a 50-acre flax field in which all the leaves and two-thirds of the bolls had been chewed off. On August 7, 60 pounds of chlordane was sprayed on 50 acres of flax in a wind of 15 miles or more per hour. There was no foliage to catch and hold the foglike spray, and a large portion of it was carried away by the wind. In tall, dense foliage such as corn, winds up to 15 miles per hour helped spread the spray without carrying it away.

In tests 13 and 14 with toxaphene, the emulsion spray was applied on newly cut alfalfa where there was much bare ground and little foliage. This work was done near Buffalo Gap, S. Dak. The spray was applied when the air was still, and the foglike spray settled over the ground in a cloud for several minutes. Excellent kills were obtained under these circumstances.

In tests 15 and 16 toxaphene was used with No. 1 distillate as a concentrated oil solution. The results were the same as for the emulsion sprays in initial kills and residual effect, but the oil spray burned the foliage severly. Because of its burning effect and its higher cost, this spray was unsuitable for practical use.

The last item in table 1 is the record of an egg survey made of an untreated 80-acre cornfield destroyed by a migration of grasshoppers from harvested small-grain fields on all sides. Most of these grasshoppers came from a field across the road to the south. No control was attempted for this field. The adult population averaged 25 per square yard in the field and 100 along the margins. These numbers were comparable to most of the other infestations where spray and poisoned-bait tests were conducted. The numbers of egg pods in all the possible egg beds affected by this infestation ran from 4.3 to 13.3 pods per square foot and averaged 9.9. The greatest differences in egg deposition occured between this untreated infestation and infestations sprayed with either chlordane or toxaphene.

Discussion

In the farm-scale tests against Melanoplus differentialis reported in this paper, the chlordane and toxaphene sprays proved much more effective than the poisoned bait. The initial and residual effects of the sprays proved to be an immediate check to further crop damage by the spreading grasshopper infestations. The infestation was almost wiped out and there was only a small amount of egg deposition.

The results with poisoned bait were not so satisfactory. Neither the spread of the infestation nor the crop damage done by the grasshoppers was successfully checked with poisoned bait, because of its poor initial kills and lack of residual action. Although sizable reductions of adult hopper populations were obtained by three or four repeated applications of bait late in the season, these treatments were ineffective in reducing egg deposition.

The main argument against the use of sprays and for the use of poisoned bait has been that the initial cost of the spray ingredients makes them much more expensive to use than the relatively cheap bait materials. As has been said before in this report, results, not costs, guided the use of both the sprays and bait in these tests. The data given in table 1 and the acreage of corn protected by the use of different insecticides were used to calculate the comparative efficiency of the insecticides. The results are shown in table 2.

Table 2.--Comparative effectiveness of chlordane and toxaphene sprays and poisoned bait applied to corn for the control of grasshoppers. Results based on one treated acre.

Insecticide	Pounds per acre	Corn acreage protected	Percent reduction of infestation	Percent of corn damaged	Average number of egg pods per square foot
Chlordane	1.23	2.37	93.0	12.8	0.8
Toxaphene	1.56	2.34	95.0	3.0	1.4
Poisoned bait	32.11	0.44	77.5	70.0	4.6

An average of 32.11 pounds of wet bait per acre served to protect less than one-fifth of the corn acreage protected by spraying 1 acre with 1.23 pounds of chlordane or 1.56 pounds of toxaphene. Furthermore, with the quantity of bait used in these tests there was less reduction in infestation, damage, and egg deposition than was obtained from the use of the other two insecticides. These factors, and the ease and certainty of obtaining control, must be considered in comparing costs. Although the bait is cheaper, the use of either chlordane or toxaphene spray might be more economical, in view of their greater efficiency in killing grasshoppers, saving crops, and preventing fall egg deposition that may result in recurrence of infestation the next year.

Judging from these experiments, an initial kill of 95 to 100 percent, with a 2-week residual effect, may be expected from the early application of 1 pound of chlordane or 1.5 pounds of toxaphene per acre against first- to third-instar nymphs. Ten to 90 percent of the infestation of any of the major economic species of grasshoppers will hatch in 15 to 20 days.

Thus with the spray remaining effective for 2 weeks, one application when 25 to 50 percent of the hatch has been completed will destroy most of the infestation. A second application may often be necessary, however, as a mopping-up operation in this early spraying of egg beds.

For late-summer spraying when the hoppers were migrating from cut small grain fields and were mostly in the fifth and sixth instars, and adult stages of development, an increase in dosage to 1.5 pounds of chlordane or 2 pounds of toxaphene per acre was apparently necessary to obtain good initial kills and effective residual action for 5 to 10 days. The need of heavier dosages for late-summer spraying is probably due to the increased size of the grasshoppers and growth of vegetation. At any period in the season a heavier dosage will lengthen the residual effect. For example, in the tests of chlordane on corn during August, 1.5 pounds per acre remained effective for 10 days whereas 2.7 pounds per acre remained effective for more than 26 days. In late-summer spraying two applications or heavier dosages on barriers apparently will be needed when there is a continuous immigration into the barrier. Heavy or repeated applications may also be necessary in other situations, as during a prolonged hatching period early in the season. Whatever the situation, the single spray application must be effective enough to stop the infestation from any further spread or damage for a few days at least and until a decision can be made as to the need for further treatment.

An attempt should always be made to kill Melanoplus differentialis infestations while the grasshoppers are still concentrated on or near the egg beds. A fully effective program of control by spraying, however, will require applications of spray to natural or crop barrier strips, when light infestations in the small-grain fields start moving into corn or other late-maturing crops as the small grains are harvested.

The heaviest rain affecting either the early- or late-season spray tests, 0.45 inch in 24 hours, had no noticeable effect on the efficiency of the spray residues from either toxaphene or chlordane. Winds up to 15 miles per hour had little effect on the results, when the foliage was a foot or more high, and dense enough to catch the foglike spray. On shorter and sparser vegetation the best results were obtained when the air was quiet. With the blower-sprayer it was possible to force the spray down on and into the short grassy vegetation on the egg beds. By elevating the nozzle of the blower and with some wind, good coverage of a strip of tall, dense corn 2 rods or 10 rows wide could be obtained with a single application.

Strips of sorghum, especially cane sorghum, and strips of corn almost invariably catch and hold any infestations moving out of adjacent small-grain fields after cutting. It is therefore feasible and economical to plant trap strips of these crops in strategic locations, and spray them to destroy infestations that may move into them from as far as a mile away. These crop strips, as well as weedy strips and the first 5 or 10 rows of cornfields were no other barriers are available, make excellent

barriers against migrating hoppers when thoroughly sprayed once or twice at the proper time. Where the outside rows of a regular corn planting are sprayed to form a barrier, the hoppers may destroy as many as five of the rows.

The results of these acutal farm tests indicate that chlordane and toxaphene sprays can be used effectively against infestations of Melanoplus differentialis and may become important control measures for this species. This report is merely a summary of the results obtained in preliminary field tests, however, and is not intended to be a general recommendation of sprays for grasshopper control. Vegetation that has been treated with either of these insecticides should not be fed to dairy cows or to animals that are being fattened for slaughter.

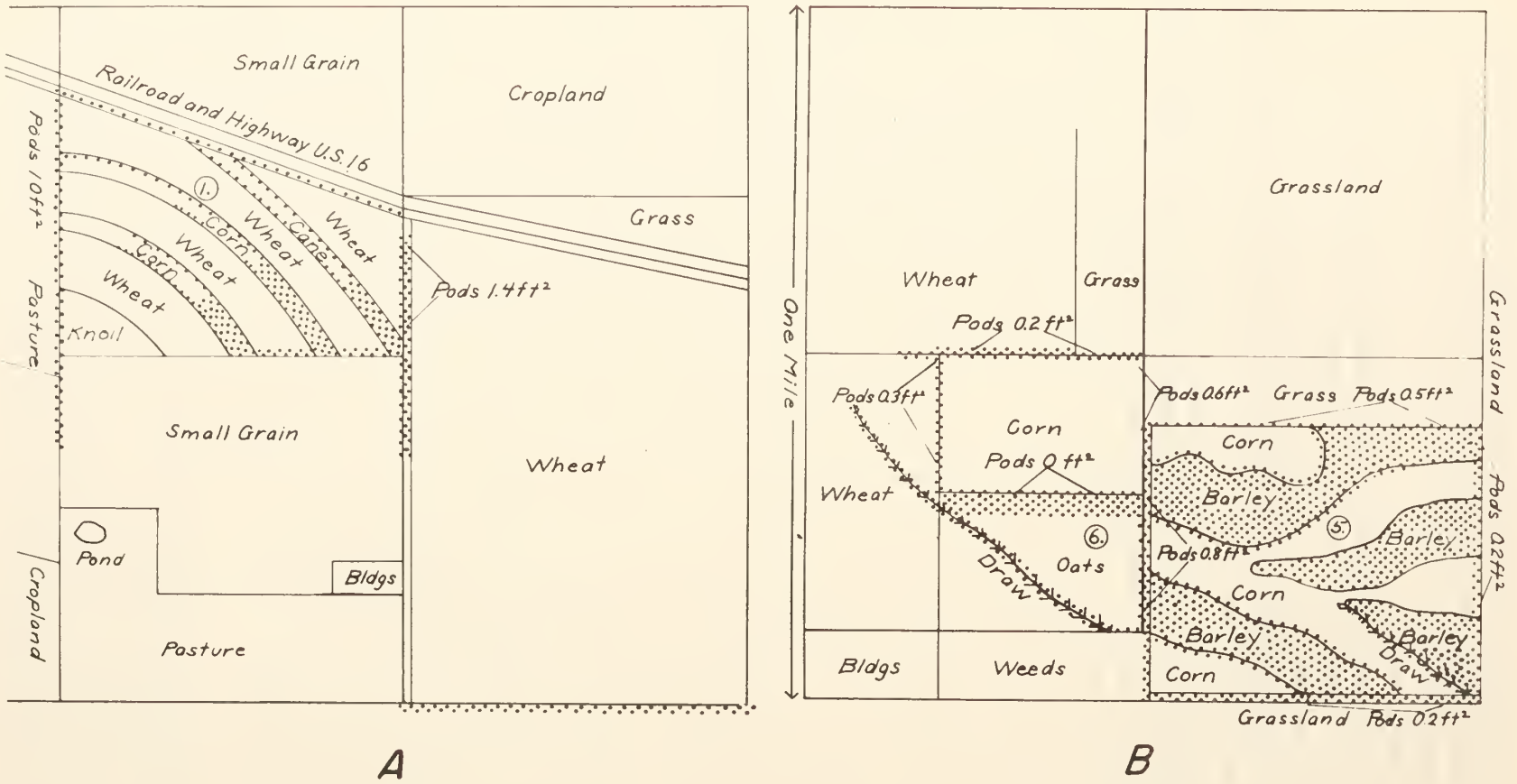

Figure 1.--Portions of areas (dotted) sprayed with chlordane emulsion in control of Melanoplus differentialis: A, Area for test No. 1; B, area for tests Nos. 5 and 6. Infestations shown in egg pods per square foot (ft.^{2}).

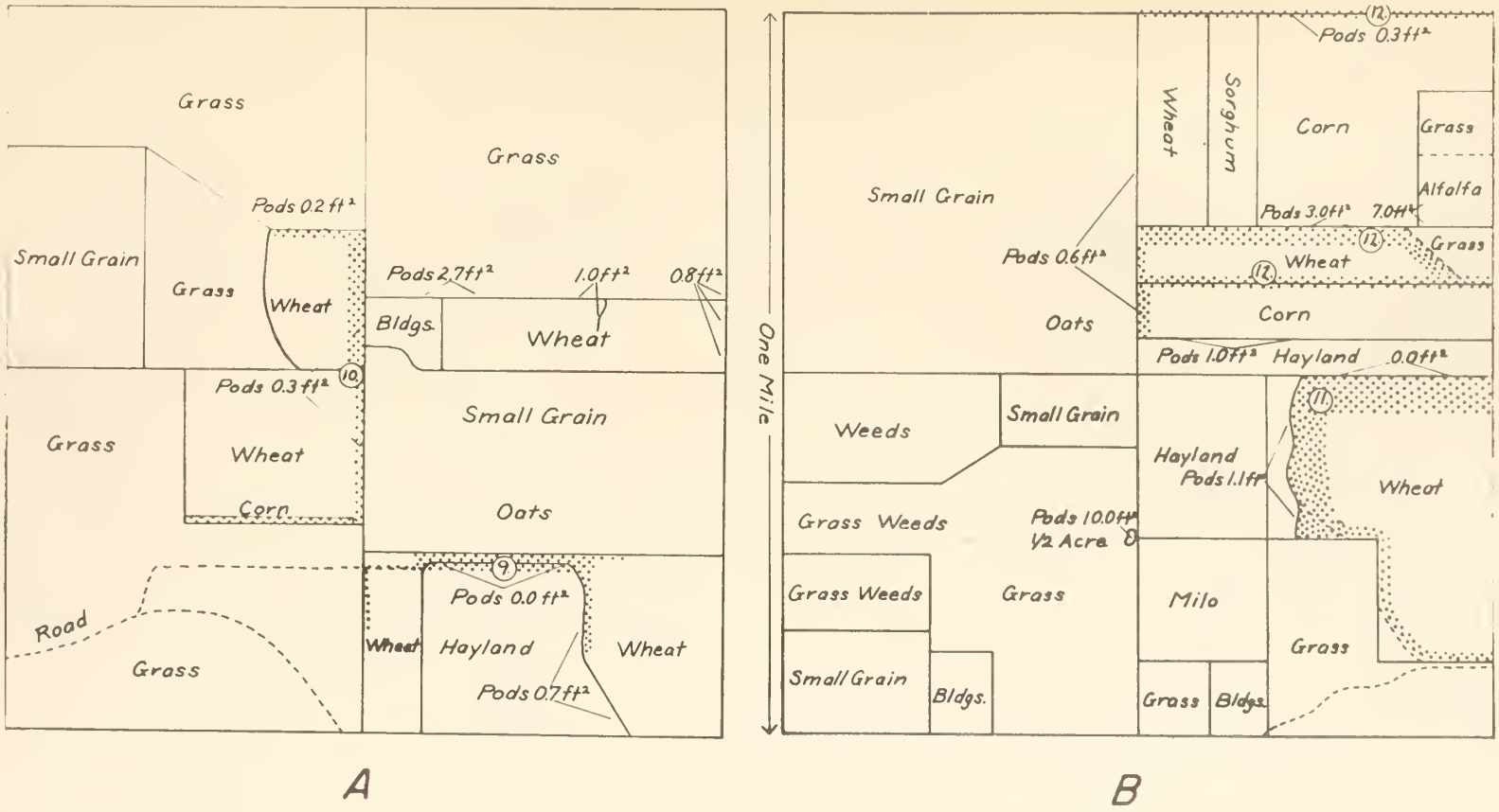

Figure 2.--Portions of areas (dotted) sprayed with toxaphene emulsion in control of Melanoplus differentialis: A, Area for tests Nos. 9 and 10; B, area for tests Nos. 11 and 12. Infestations shown in egg pods per square foot (ft.^{2}).

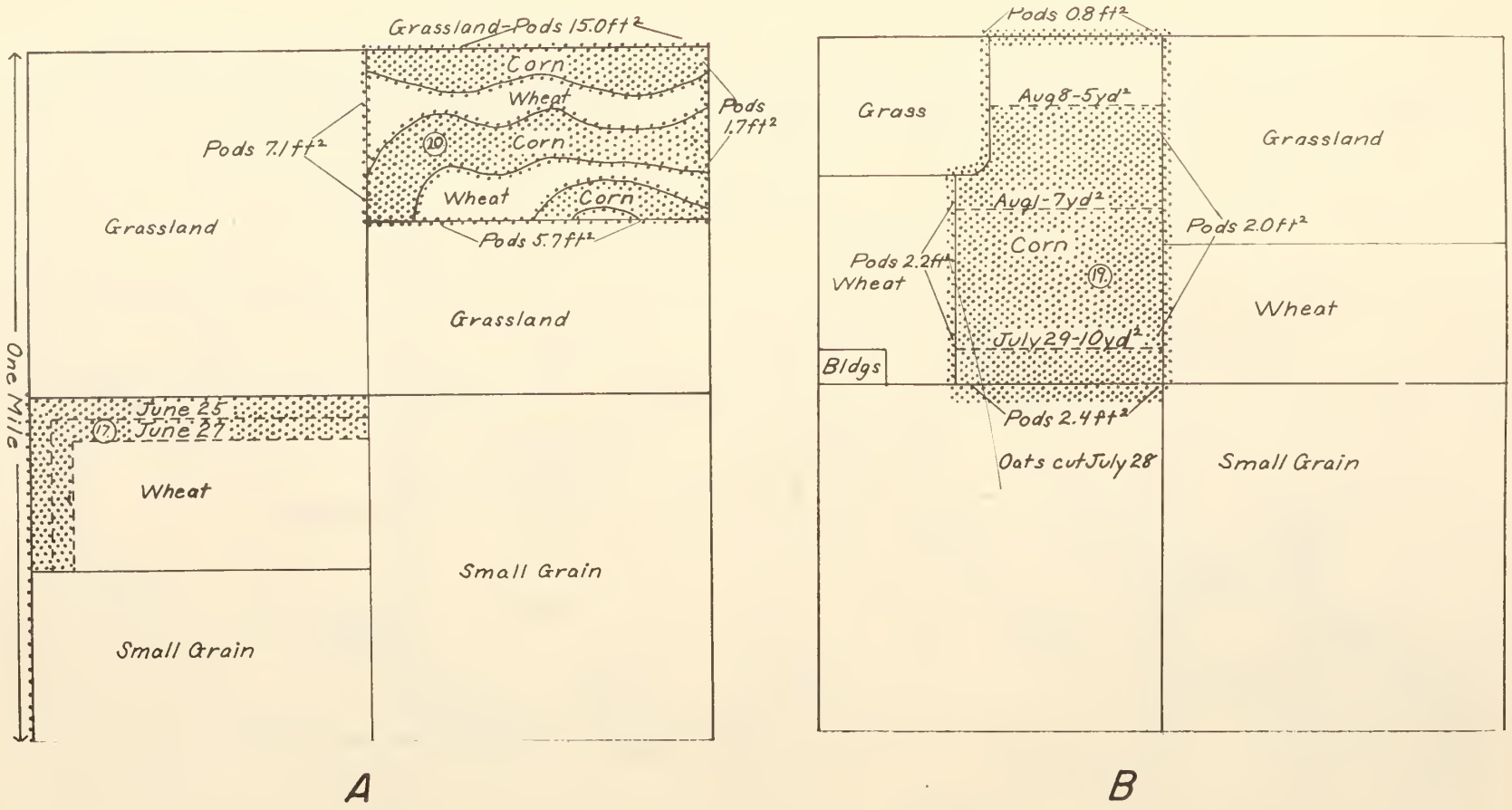

Figure 3.--Portions of areas (dotted) treated with poisoned bait in control of Melanoplus differentialis: A, Area for tests Nos. 17 and 20; B, area for test No. 19. Infestations shown in egg pods per square foot (ft.^{2}).